EMBEDDED HEALTH MONITORING FOR GLASS LIKE ARMOR

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ABSTRACT

The authors describe a technique they developed to perform optical non destructive evaluation of glass like armor which is inexpensive, available everywhere and the output is easy to understand.

1. INTRODUCTION

The U.S. Army has developed a type of armor protection for vehicles which consists of several layers of glass plates. The plates are inserted in a plastic box and epoxy material is used to prevent the plates from being damaged by moving inside the box. To prevent the plates from chipping, the plastic box is encased in a steel box. Typical non destructive evaluation for this type of armor is to check for cracked plates using a high intensity X-ray machine. However the X-ray equipment is usually not available in theater. Dismounting the cubes from the vehicle for the purpose of inspection is also inconvenient and labor intensive. The authors have developed a new optical method of NDE which is inexpensive, available everywhere (the testing apparatus is inside the cube) and the output is readily understandable.

2. GENERAL DESCRIPTION OF THE TECHNIQUE

The glass plates are transparent, and light is readily transmitted through them. The plates are such that light waves that are incident and transmitted from one side of a glass layer to the other are diffused if the layer has a crack, and that the light intensity changes drastically at the crack interfaces.

Fig. 1: Incandescent light illuminated glass layers

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **13 FEB 2012**	2. REPORT TYPE **Journal Article**	3. DATES COVERED **13-02-2012 to 13-02-2012**

4. TITLE AND SUBTITLE **EMBEDDED HEALTH MONITORING FOR GLASS LIKE ARMOR**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Thomas Meitzler; Samuel Ebenstein; Thomas Reynolds; Jason Schrader**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC ,6501 E.11 Mile Rd,Warren,MI,48397-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER **#22582**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC, 6501 E.11 Mile Rd, Warren, MI, 48397-5000**	10. SPONSOR/MONITOR'S ACRONYM(S) **TARDEC**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **#22582**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The authors describe a technique they developed to perform optical non destructive evaluation of glass like armor which is inexpensive, available everywhere and the output is easy to understand.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

In Fig. 1 above a flashlight was used to illuminate the top two layers of the cube. The light intensity is relatively uniform in the top layer; however in the second layer there is a sharp discontinuity in the light intensity. (The second layer has a crack in it.) The authors measured the light output with photo transistors at five equidistant locations along each layer then calculated delta, the maximum change in slope in each layer.

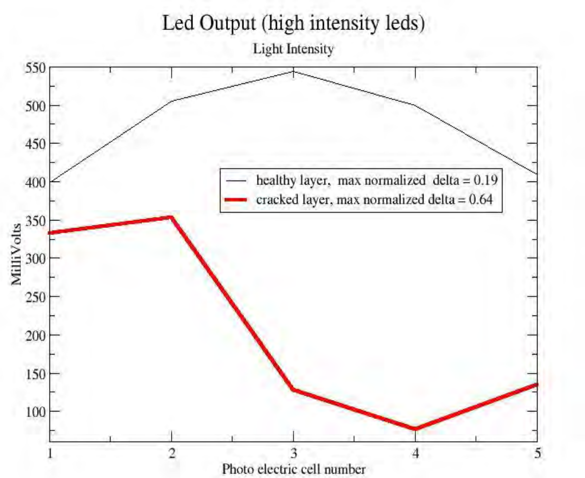

Fig. 2: LED output of healthy and damaged layers

Two "identical cubes" were fabricated and LED's[†] were installed on one side of the cube and photo transistors on the other side to measure the transmitted light through the layers. One of the layers was cracked. Unfortunately differences in resin flow and air bubbles made it difficult to distinguish between the healthy and the cracked cube based on the method described above. The differences in manufacturing variability caused the method to not be reliable. The first method wasn't sufficiently robust to accommodate slight variations in manufacturing. In order to overcome this difficulty it was decided to develop a method which met the following criteria:

- A method is needed that is not sensitive to manufacturing variability in building the cube.
- Doesn't require strict manufacturing tolerances or an "ideal part".
- Requires very little data collection and computation.
- All computer components can fit in a confined space which can be inserted between the armor plates and the plastic cube containing the armor plates.
- The method should be robust.

The data analysis should be quick and easy to use and interpret.

[†] Reference herein to any specific commercial company, product process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the Department of the Army (DoA). The opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or the DoA, and shall not be used for advertising or product endorsement purposes.

Fig.'s 3a and 3b below show an undamaged and damaged glass cube from the top.

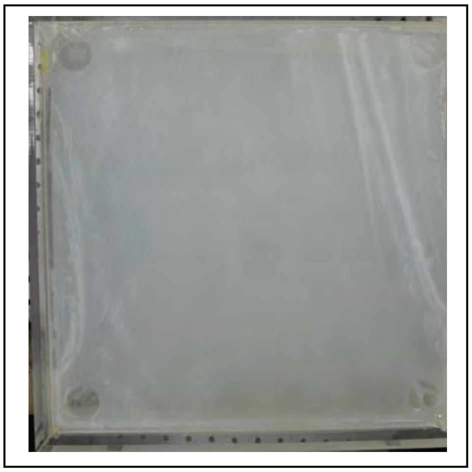

Fig. 3a: Top down Image of a healthy plate

Fig. 3b: Top down Image of a damaged plate

The following diagram in Fig. 4 shows the hardware configuration.

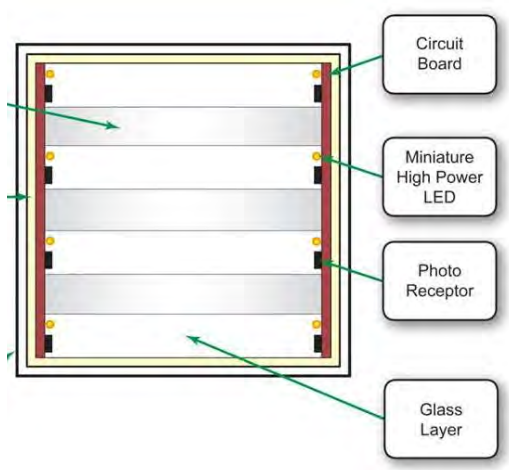

Fig. 4: Embedded NDE configuration

As shown in Fig. 4 above, the cube has 4 glass layers. The entire cube is encased in a plastic box. A filler is used to prevent the glass layers from movement in the box. The plastic container is then encased in a steel container. The circuit board needs to fit in the space between the glass plates and the plastic box.

Fig. 5: Image of the circuit board with a quarter coin for reference to show the board thickness.

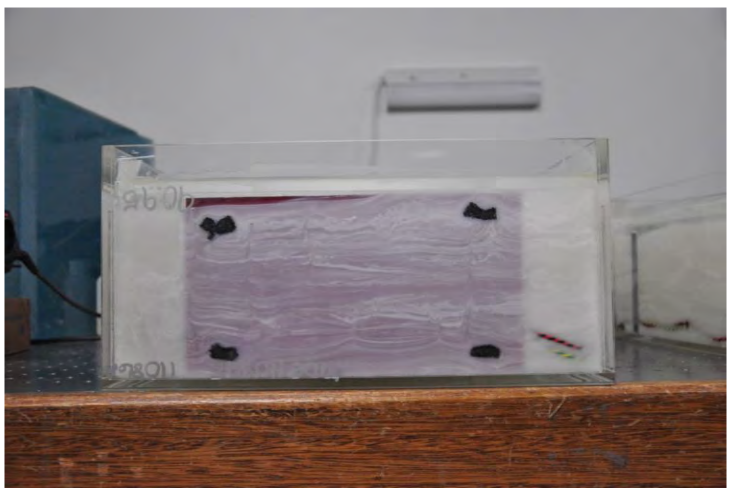

Fig. 6: Side view of the glass cube and embedded circuit board

The cube contains two identical circuit boards which are placed on opposite sides of the cube. Each circuit board is aligned with the glass plates so that it has four LED's and four phototransistors used for detection per layer. The LED's on one board transmit the light that is received by the phototransistors on the board on the opposite side. By using two boards there is redundancy built into the system so that if a LED or phototransistor is defective on one side of the board there is an identical device on the opposite side.

Let us consider how the data is collected for layer 1 for one side of the cube. The other layers are similar. The first LED in layer 1 is activated and the readings of the 4 phototransistors in layer 1 on the opposite side are collected by a 10 bit A/D converter and stored in computer memory. This process is then repeated for other 3 LED's in layer 1. We thereby obtain 16 readings for layer 1 from one side of the cube, and similarly 16 readings from the other side of

the cube. Since each board has 4 layers we collect 64 readings from each board, for a total of 128 readings from a single test of the board. Because there is some random noise in each reading, a procedure is needed to remove this variability. One way to remove this noise and account for differences due to environmental changes is to create a database that will capture the status of the cube when it is known to be healthy (after manufacture and before it is fielded).

How the database is created

A database is needed that contains information on how the light is transmited and registered by the LED's and phototransistors when the cube is known to be undamaged (right after manufacture) to use as a reference. The cube is measured repeatedly and the average of the 32 readings over time are measured and the averages in 32 variables, 4 variables per layer, 4 layers per board, and a total of two boards are stored. Also computed are the 32 standard deviations for these variables. Now repeat the testing under various ambient conditions to determine the average value for each variable, and the deviation in each variable. It may happen that a standard deviation of 0 is obtained, since the phototransistors only produce values between (0-1023) because they are read by a 10 bit A/D converter. In this case or whenever the standard deviation is less than 1, this values is arbitrarily set it to 1. This set of 32 averages and 32 standard deviations is then stored in the cube in a non-volatile memory chip. If a phototransistor or LED is damaged during construction of the cube, this fact will implicitly be stored in the cube database, because it will automatically effect the averages and standard deviations associated with that particular phototransistor or LED.

Determining cube health

At some time in the future it will be desired to check the health of the cube, and to what extent it is damaged. The cube is tested once and to obtain 32 variables. A metric is defined as follows: let $1\_ave_{i,j}$ represent the average of a photo sensor where i is the layer number $1 \le i \le 4$ and j is the sensor number, $1 \le j \le 4$. $1\_ave_{i,j}$ represents the averages for sensor board 1, while a similar variable $2\_ave_{i,j}$ represents the averages for sensor board 2. Now compute the metric value at i,j for all i,j pairs for board 1 as follows, $m_{i,j} = |(1\_ave_{i,j} - x_{i,j})/1\_sdev_{i,j})|$ where $1\_sdev_{i,j}$ is the standard deviation associated with $1\_ave_{i,j}$ as computed above and | | is the absolute value of the variable. The max deviation for layer 1 is compted as as follows: for each layer from $1 \le i \le 4$

max1,i = max(mi,1, mi,2, mi,3, mi,4), and we can compute max1,i in an analogous manner. If either max1,i or max2,i is greater than a threshold value we say that layer i is damaged. In practice a threshold value of 25, has distinguished between healthy and damaged layers as can be seen from the following plots:

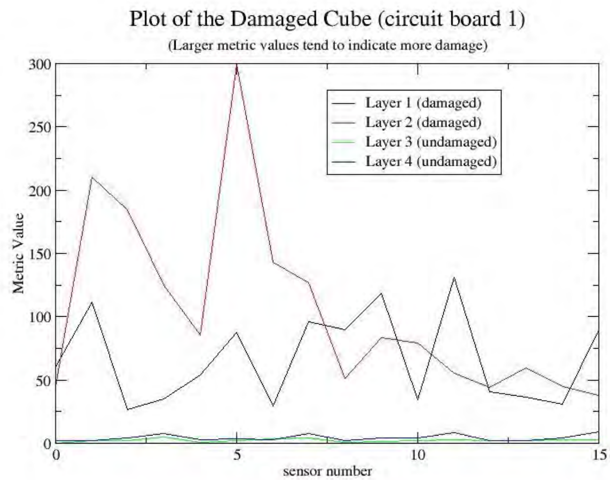

Fig. 7: Plot of the metric of 4 layers of the damaged cube using the values from circuit board 1

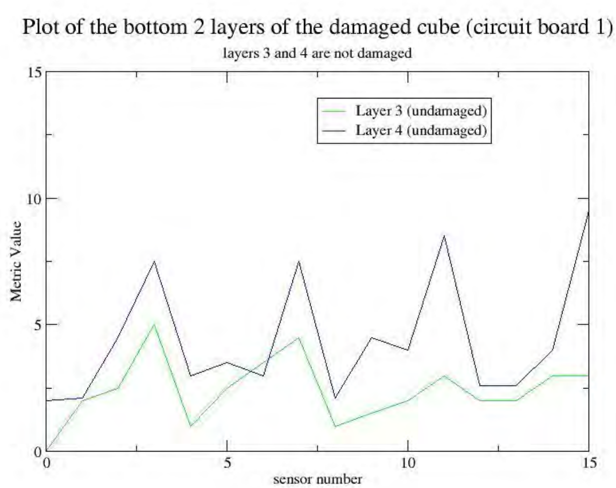

Fig. 8: Plot of the metric of the bottom 2 layers of the damaged cube

We can compare these graphs with that of the undamaged cube below in Fig. 9.

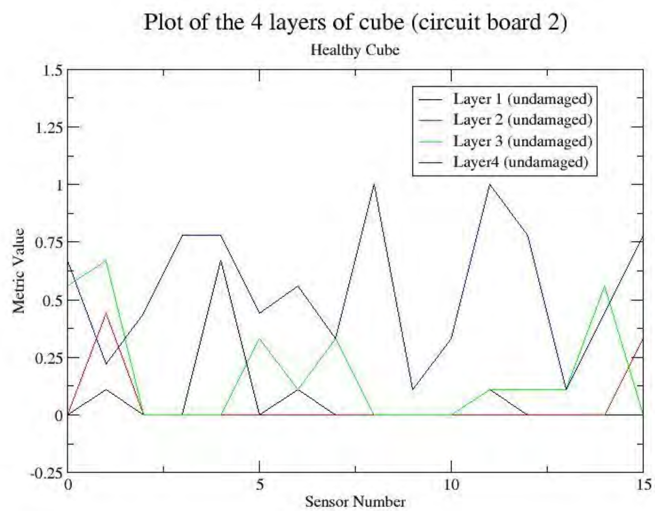

Fig. 9: A plot of the 4 layers of the undamaged cube from circuit board 1

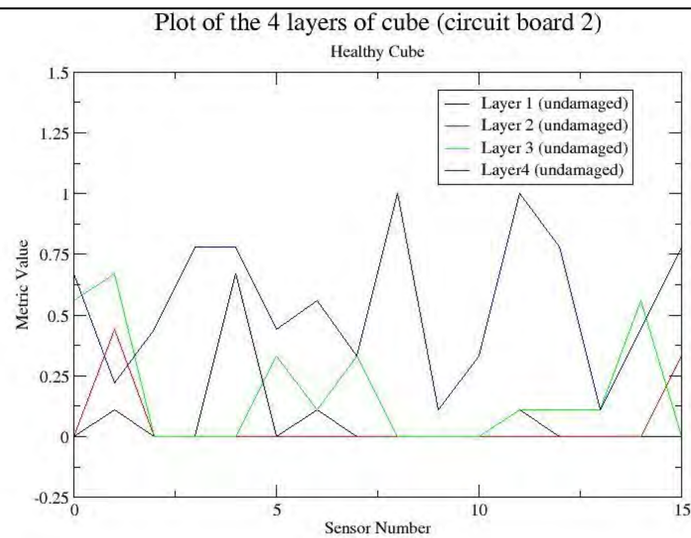

Fig. 10: A plot of the 4 layers of the undamaged cube from circuit board 2.

3. CONCLUSIONS

The authors have shown a technique and method to determine the health or glass pates without the use for x-rays. The technique has a patent pending. Future plans are for integrating this technology onto vehicles for environmental testing.

4. REFERENCES

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